

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

WO 96/35306

(51) International Patent Classification 6 :
H04Q 7/38, G01S 5/10

A1

(11) International Publication Number:

(43) International Publication Date: 7 November 1996 (07.11.96)

(21) International Application Number: PCT/GB96/01039

(22) International Filing Date: 1 May 1996 (01.05.96)

(30) Priority Data: 9508884.5 2 May 1995 (02.05.95) GB

(71) Applicant (for all designated States except US): TELECOM SECURICOR CELLULAR RADIO LIMITED [GB/GB]; 260 Bath Road, Berkshire SL1 4DX (GB).

(72) Inventors; and
(75) Inventors/Applicants (for US only): MUNDAY, Peter, Robert [GB/GB]; 8 Candleford Close, Bracknell, Berkshire RG12 2JZ (GB). GOETZ, Ian [GB/GB]; 6 Turner Grove, Kesgrave, Ipswich, Suffolk IP5 7XQ (GB). GANNON, Stephen, Mark [GB/GB]; 98 Bois Moor Road, Chesham, Buckinghamshire HP5 1SS (GB).

(74) Agent: LIDBETTER, Timothy, Guy, Edwin; BT Group Legal Services, Intellectual Property Dept., 8th floor, 120 Holborn, London EC1N 2TE (GB).

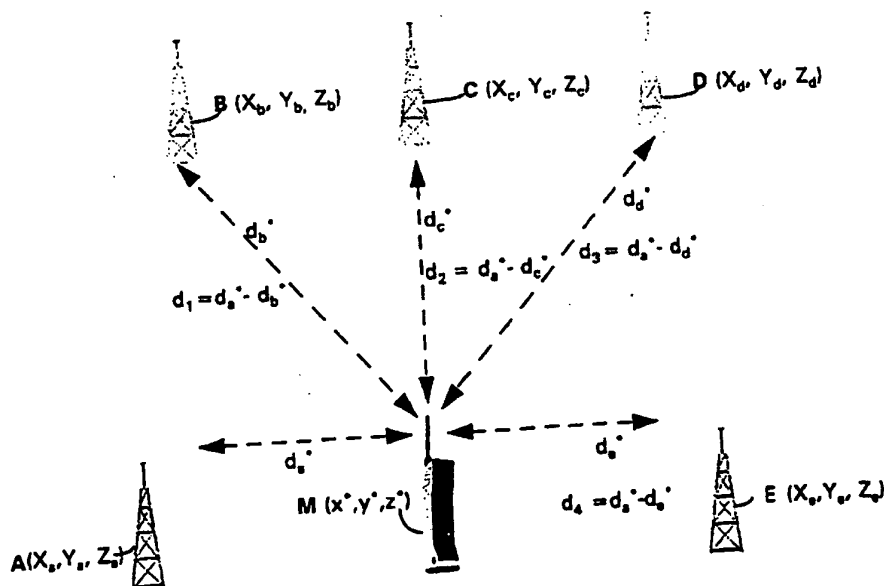
(81) Designated States: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published

With international search report.

Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: CELLULAR RADIO LOCATION SYSTEM



(57) Abstract

The location of a mobile unit M of a cellular radio system is determined by determining the differences in timing of a characteristic feature of the transmission of the control channel of each base station A, B, C, D, E as measured at the mobile unit. Preferably the characteristic feature is the training sample already used by the mobile unit in cellular systems to measure signal strength in order to inform handover decisions. By determining the differences between time of arrival of transmissions from four base stations A, B, C, D, position in two dimensions can be derived without prior knowledge of the actual distance to any of the base stations. A fifth base station E allows position in three dimensions to be determined.

BEST AVAILABLE COPY

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia	GB	United Kingdom	MW	Malawi
AT	Austria	GE	Georgia	MX	México
AU	Australia	GN	Guinea	NE	Niger
BB	Barbados	GR	Greece	NL	Netherlands
BE	Belgium	HU	Hungary	NO	Norway
BF	Burkina Faso	IE	Ireland	NZ	New Zealand
BG	Bulgaria	IT	Italy	PL	Poland
BJ	Benin	JP	Japan	PT	Portugal
BR	Brazil	KE	Kenya	RO	Romania
BY	Belarus	KG	Kyrgyzstan	RU	Russian Federation
CA	Canada	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic	KR	Republic of Korea	SE	Sweden
CG	Congo	KZ	Kazakhstan	SG	Singapore
CH	Switzerland	LI	Liechtenstein	SI	Slovenia
CI	Côte d'Ivoire	LK	Sri Lanka	SK	Slovakia
CM	Cameroon	LR	Liberia	SN	Senegal
CN	China	LT	Lithuania	SZ	Swaziland
CS	Czechoslovakia	LU	Luxembourg	TD	Chad
CZ	Czech Republic	LV	Latvia	TG	Togo
DE	Germany	MC	Monaco	TJ	Tajikistan
DK	Denmark	MD	Republic of Moldova	TT	Trinidad and Tobago
EE	Estonia	MG	Madagascar	UA	Ukraine
ES	Spain	ML	Mali	UG	Uganda
FI	Finland	MN	Mongolia	US	United States of America
FR	France	MR	Mauritania	UZ	Uzbekistan
GA	Gabon			VN	Viet Nam

CELLULAR RADIO LOCATION SYSTEM

This invention relates to radio location systems. A number of systems are being developed for identifying the location of a mobile unit, using radio propagation characteristics. One such system is the Global Positioning System (GPS), in which a portable unit obtains a position fix using radio transmissions from space satellites. This system is highly accurate, but requires special equipment, and is unreliable in locations having poor visibility of the sky, because several widely separated satellites must be in line-of-sight relationship with the handset for a fix to be obtained.

Several proposals have been made for systems which use the radio propagation characteristics of a cellular radio system to provide a position fix for a cellular radio mobile unit. This would allow the mobile unit itself to act as a position finding device. As is well known, cellular radio systems allow a user having a portable handset (a "mobile unit") to make and receive telephone calls, either to another mobile unit or to a conventional fixed termination, by means of a radio link. The radio link is established between the mobile unit and one of a network of fixed radio base stations distributed over the area to be covered. The system allows any mobile unit to communicate through any of the base stations; usually the mobile unit will communicate through the base station providing the best quality radio signal.

Because the mobile unit may move during the course of a call, it can become necessary for it to move out of range of the base station with which the call was initially established. Cellular radio systems therefore include handover systems to allow communication to be established with a second base station, and dropped from the first, without interrupting the call itself as perceived by either party to the call. In the system known as GSM, (Global System for Mobile communications), the mobile unit frequently monitors the BCCH (Broadcast Control Channel) of the surrounding base stations in order to establish which base station is providing the best signal, and therefore through which base station a new call should be established, or whether a handover should be initiated. This process occurs in both idle and active modes, i.e. there is no need for the user to make a call.

Developments in GPS technology mean that a highly accurate synchronisation source can now be implemented relatively cheaply at each cellular radio base site. A good source of synchronisation has a number of benefits, these include; improved handover, an ability to reduce the effect of interference between neighbouring base stations, and enabling highly accurate radiating frequencies on the radio interface. It should be noted that unlike simple broadcast time signals, the GPS synchronisation signal takes the position of the GPS receiver into account, and can therefore compensate for the time lag caused by the finite speed of radio waves.

European patent Specification EP0320913, (Nokia), describes a system in which timing pulses derived from the GPS system are transmitted from each of three or more base stations, and their different arrival times at the mobile unit are used to identify the position of the unit. This prior art system requires the mobile unit to interrogate each base station in turn, which requires it to hand over communication between the various base stations in order to carry out this interrogation. This requires the use of several traffic channels, or an auxiliary channel and also requires that reliable radio communication can be established with each nearby base station.

In International Patent Application WO95/00821 (Omniplex) each base station transmits synchronised packet data signals. The mobile unit monitors all the base stations simultaneously, which either requires a mobile unit capable of receiving several radio frequencies at once, or that all the base stations transmit their data packets on the same channel. Neither of these features are conventional in a cellular radio system.

Both of these systems also require the transmission of special timing or synchronisation pulses from the cell sites (base stations) to the mobile unit, and the recognition of these pulses by the mobile unit. This requirement not only imposes a signalling overhead on the mobile unit, but it requires additional functionality in the mobile unit to recognise the timing pulses.

According to the invention, there is provided a method of determining the location of a mobile unit of a cellular radio system having a plurality of base stations, comprising the steps of determining the differences in timing between the base stations' transmissions as measured at the mobile unit, determining from the

timing differences the differences in the distance of the mobile unit from each of
the base stations, and deriving the location of the mobile unit from the differences
in distance so determined, characterised in that the time division frame structures
of the control channels of at least some of the base stations within radio range of
5 the mobile unit are synchronised, and the mobile unit determines the differences in
timing at the mobile unit of a characteristic feature of the time division frame
structure broadcast by the control channel of each base station.

By using the control channel the mobile unit is able to make use of the
existing radio link quality monitoring systems used to establish whether a handover
10 should take place, and does not need to establish full communication with any of
the base stations.

Preferably the characteristic feature used is a training signal transmitted by
each base station, which can be correlated with a reference training signal stored
by the mobile unit, such as the "synchronisation burst" (SCH), and its correlation
15 process which already form part of the GSM standard for the purpose of
characterising the radio path for the purpose of eliminating multipath interference.
The method of the invention can therefore make use of these existing signals and
correlation analysis programming. However, for position determination it is
preferred that the system should use the first identified correlation of the reference
20 signal, rather than the strongest as is used for handover determination. This
ensures that the most direct signal path, rather than a stronger but more indirect
path, is used for distance calculation.

The derived location may also be time averaged to minimise the effects of
spurious results from reflected signals, which would make the apparent distance
25 between the base station and the mobile unit longer than it really is.

The derived location may be communicated via the cellular radio network
to a remote user, instead of to the user of the mobile unit itself. An alarm signal
may be transmitted if the derived location corresponds to a predetermined location.

According to another aspect of the invention, there is provided a mobile
30 unit for use with a cellular radio system, the mobile unit comprising apparatus for
determining the position of the mobile unit; the apparatus comprising means for
detecting timing differences between signals received from different radio base
stations, and means for determining, from the timing differences, the differences in

the distances of the mobile unit from each of the base stations; and means for deriving, from the differences in distance, the location of the mobile unit, characterised in that the mobile unit has means for determining the differences in timing at the mobile unit of a characteristic feature of a time division frame structure broadcast synchronously by the control channel of each base station.

The mobile unit may further comprise means for receiving data from the currently serving base station concerning base stations within radio range of the mobile unit, the information including the geographical locations of the base stations.

10 The cellular radio network may be complementary to the mobile unit of the second aspect of the invention as defined above. Alternatively, the location determination functions may be performed by the network itself. Accordingly, the cellular network may comprise means for determining the difference in timing between signals transmitted by the base stations as measured at the mobile unit;
15 means for determining, from the timing differences, the differences in the distances of the mobile unit from each of the base stations; and means for deriving, from the differences in distance, the location of the mobile unit, being characterised in that the base stations have broadcast control channels operating with synchronised time division frame structures having a characteristic feature for
20 detection by the mobile units, and in having means for receiving from the mobile unit an indication of the arrival time at the mobile unit of the characteristic feature from each base station.

According to a further aspect of the invention, there is provided apparatus for determining the position of a mobile unit using a cellular radio system having a
25 plurality of base stations, means for determining the differences in timing between the operation of the base stations as measured at the mobile unit; means for determining, from the timing differences, the differences in the distances of the mobile unit from each of the base stations; and means for deriving, from the differences in distance, the location of the mobile unit, characterised in that the
30 system comprises means for synchronising the time division frame structures of control channels broadcast by at least a plurality of the base stations within radio range of the mobile unit, and the mobile unit has means for determining the differences in timing at the mobile unit of a characteristic feature of the time

division frame structure broadcast by the control channel of each base station. The time difference measuring means, distance difference determining means and location deriving means may each form part of the mobile unit or of the fixed network. If in the mobile unit, this unit may further comprise means for receiving
5 data from the currently serving base station concerning base stations within radio range of the mobile unit, the information including the geographical locations of the base stations.

In a further aspect, there is provided a position-finding device comprising means for determining the geographical location of the device, means for
10 identifying a predetermined geographical location, and alarm means for signalling to a user that the geographical location of the device corresponds to the predetermined geographical location or area.

In existing GSM systems each base station transmits a control channel (BCCH) having a TDMA frame structure. This frame structure is made up of
15 "multiframes" each of 235.38 milliseconds. Each multiframe has a substructure of fifty-one frames, each frame having eight bursts. Each burst is made up of three "tail" bits, 142 information bits, three more "tail" bits, and a guard period equivalent in duration to $8\frac{1}{4}$ bits. The frame is thus $156\frac{1}{4}$ bits in duration, and each bit has a duration of approximately 3.9 microseconds, so a burst has a
20 duration of 0.577 milliseconds. The frames in each multiframe are conventionally numbered 00 to 50, of which five are frequency control frames (FCCH), (00, 10, 20, 30 and 40); and five are synchronisation frames (SCH); 01, 11, 21, 31, 41. The interval between the synchronisation frames is therefore generally 46.15 msec, (80 bursts), but the interval between frames 41 and 01 has a longer
25 duration of 50.77 msec (88 bursts) because of the presence of the extra frame 50. The synchronisation frames each include a training sequence which is used in this embodiment of the invention as the characteristic feature.

In GSM, the use of time division multiple access (TDMA) means that the mobile station and the serving base station have to be highly synchronised. For the
30 mobile unit to decode the identity code BSIC of a base station, it has to briefly synchronise itself with the base station. Consequently, the mobile unit always has an indication of by what fraction of a frame (i.e., how many bits) each of the neighbouring base stations differ from the serving base station, as seen by the

mobile unit. If the frame cycles of all the base stations were to be absolutely synchronised, (i.e. all the base stations simultaneously transmit the same part of the frame) the amount the mobile unit would have to shift its frame structure (relative to the serving base station) to decode the BSIC of the other base stations
5 would be purely a function of the difference in path length between the serving base station and its neighbours. In existing systems mobile units are synchronised to their serving base stations to better than $\frac{1}{4}$ bit, 0.923 microseconds, which, at the speed of light (3×10^8 m/s), corresponds to a resolution of 277m. This accuracy can be significantly improved upon for location purposes by using the
10 data present in the equaliser of the mobile unit.

In GSM practice, the frame structure of each base station is not synchronised in the absolute sense, but only in the relative sense that for each base station there is some point in the frame structure which is synchronised with the external synchronisation signal. Thus the timing of the frame structures of the
15 base stations differ from each other by an arbitrary but constant amount, referred to herein as the "offset". The term "synchronised", as used in this specification, is used in this relative sense (i.e. differing by a constant amount), unless the context clearly demands otherwise.

It would be possible to reconfigure the GSM system such that the base
20 stations are all synchronised in the absolute sense. However, in a preferred arrangement, for each base station the respective offset is subtracted from the arrival time at the mobile unit of the characteristic feature of the frame to obtain the difference between the distance that base station is from the mobile unit and the distance the serving base station is from the mobile unit. These calculations
25 may be performed in the fixed part of the network, but in a preferred arrangement data relating to the offset associated with each base station is transmitted from the serving base station to the mobile unit, and the timing difference is determined by the mobile unit from said offset data and the arrival times of the characteristic feature from each base station. Accordingly, another aspect of the invention
30 provides a cellular radio network for use with the mobile units defined above, comprising a plurality of base stations operating with control channels broadcasting synchronous time division frame structures, means for identifying which of the base stations are in radio range of a specified mobile unit, and means

for transmitting data relating to the location and synchronisation offsets of each such base station to the mobile unit.

The timing differences provide the differences in path lengths between the various base stations, however they do not provide an absolute path length. In the prior art systems described above, the timing of signals from a minimum of three base stations is stated to be sufficient to provide a unique position fix (in two dimensions). In order to achieve this, it is necessary to know not only the difference in arrival times of the signals from the different base stations, but also their absolute arrival times relative to some fixed timescale. This requires the mobile unit to have a clock synchronised with those of the base stations. The base stations can be synchronised using the GPS system, but the mobile units cannot themselves be synchronised to the GPS system unless they too incorporate GPS receivers, thereby re-introducing the complexity sought to be avoided by using the cellular radio characteristics.

It has been suggested that timing advance be used to determine distance from the serving base station. Timing advance is the amount by which a mobile unit is instructed by the serving base station to advance its transmissions relative to the signals received by the mobile unit, to allow the transmissions from the mobile unit to arrive at the base station at its allocated point in the TDMA frame. The timing advance corresponds to the time taken for radio waves to cover the out-and-back distance between the base station and the mobile unit, i.e. twice the path length. However, the timing advance is only determined when a mobile unit has a call in progress. Furthermore, the timing advance is determined for the strongest signal, which is not necessarily the most direct if multipath interference is present, and its accuracy is also relatively coarse.

Instead, in one preferred arrangement according to the invention the differences in timing between at least four base stations are determined (conveniently these are the differences between the currently serving base station and each of three neighbouring ones), thereby allowing the determination of the absolute location of the mobile unit in two dimensions. As will be described below, the use of four base stations provides a unique result in two dimensions, without the need for an absolute reference in the mobile unit. In another preferred arrangement the differences in timing between at least five base stations (the

serving base station and four others) are determined, thereby allowing the determination of the absolute location of the mobile unit in three dimensions. This latter arrangement is to be preferred if the differences in the altitudes of the base stations and/or the mobile unit are large in relation to the overall accuracy of the
5 system.

Embodiments of the invention may nevertheless use timing advance information to supplement the basic method in circumstances where fewer than the minimum number of base stations are detected by the mobile unit. Other supplementary information may also be used where circumstances require, such as
10 information relating to the direction of the mobile unit relative to the antenna. If one or more of the plurality of base stations in the cellular radio system have a very limited range, the method may comprise an additional step wherein if the mobile unit is recognised as being within range of one of said limited-range base stations the location of the mobile unit is determined to be the location of said
15 limited-range base station.

An embodiment of the invention will now be described with reference to the drawings in which:

Figure 1 shows part of a cellular radio system;

Figure 2 is a schematic illustrating part of the system of Figure 1 in more
20 detail, and indicating the various parameters used in the calculations carried out in the method of the invention;

Figure 3 illustrates multipath propagation; and

Figure 4 shows a plot of correlation against time for a training sequence;

Figure 1 shows a cellular radio system including a mobile unit M, a base
25 station A, currently serving the mobile unit M, and six neighbouring base stations B, C, D, E, F, G. Each base station is shown as having a hexagonal coverage area, or "cell", but in practice the cells are more irregular because of topographical reasons, and base station siting. Moreover, the propagation characteristics of radio waves mean that coverage areas overlap in practice, and the mobile unit can
30 detect signals from several nearby base stations, albeit less strongly than from the currently serving base station A. For the purposes of this illustration, it will be assumed that the mobile unit M can detect the BCCH (control channel) of base stations A, B, C, D, and E at least.

The coverage area of base station A is shown subdivided into three 120 degree sectors A1, A2, A3, each of which is served by a respective sector antenna at base station A, having its own channel allocation.

Also within the coverage of base station A there is a microcell H. This is a
 5 cell having its own low power (and therefore short range) base station, provided to serve a limited area having a high demand for call traffic, and/or which is poorly served by the main cellular structure, for example because of tall buildings.

In Figure 2, there is shown the mobile unit M and five base stations A, B, C, D, E are represented, together with their co-ordinates in three dimensions (X_a ,
 10 Y_a , Z_a ; X_b , Y_b , Z_b ; X_c , Y_c , Z_c ; X_d , Y_d , Z_d ; X_e , Y_e , Z_e), and the distance of the mobile unit from each base station d_a , d_b , d_c , d_d , d_e , respectively. The unknown co-ordinates of the mobile unit M are represented as (x,y,z) .

For illustrative purposes the embodiment will be described as operating according to the GSM standard, using GPS data, but this is not intended to be
 15 limitative. In GSM, each base station, (for example, the base station A) holds information relating to itself and six nearby base stations B, C, D, E, F, G. For the purpose of the present invention only four nearby base stations B, C, D, E of the six are used, the four in question generally being those providing the strongest signal at the mobile unit M. The base station transmits the data to the mobile unit
 20 M on its BCCH (Broadcast Control Channel). This data includes the radio frequency of each base station's BCCH, allowing the mobile unit to periodically sample the signal quality of each BCCH, and allow handovers to take place based on the results of this sampling.

In this embodiment of the invention information additional to that required
 25 by the GSM system is transmitted to the mobile unit, either over the BCCH or in a separate data message. This information includes the location of each of the base stations A, B, C, D, E and their relative frame offsets (as defined above). This offset indicates how the timing of the TDMA frame structure relates to a reference timeframe, which may be the time frame of the serving base station A, or of
 30 universal reference.

The radio link between the mobile unit M and the base station A is a time division multiple access (TDMA) system, in which different mobile units communicate with the base station A on the same radio frequency, at different

times. At times when the base station A is transmitting to other mobile units (not shown), the mobile unit M monitors the BCCH frequencies of the nearby base stations B, C, D, E, (F, G) as identified to it by the base station A.

Each base station periodically transmits a training sequence (SCH).

- 5 Specifically, in GSM, the SCH is transmitted five times in each multiframe of the BCCH, in TDMA frames 01, 11, 21, 31, and 41. This training sequence corresponds to a sequence stored in the mobile unit, which is arranged to identify correlations between the stored sequence and the BCCH transmissions, thereby allowing the mobile unit and base station to be synchronised and an estimate of
10 the signal quality to be made.

Figure 3 illustrates a phenomenon known as "multipathing". In a typical environment radio signals may propagate between a base station A and a mobile unit M by a number of different paths, as a result of reflections and refraction caused by buildings and other obstructions. These paths are, in general, of
15 different length; for example a direct path 41 is shorter than a path 42 reflected by a building 40. The correlation of the training sequence may therefore identify more than one correlation, occurring at different times. This is illustrated in Figure 4, in which there is a first correlation 31 at time t_{31} and a second, stronger correlation 32 at time t_{32} . This situation can occur when the direct path 41 is subject to
20 attenuation, for example by foliage, and the direct path is not attenuated. In the example of Figure 3, a strong indirect signal 42 will occur if the building 40 is a good reflector of radio waves.

For the purpose of assessing suitability for handover, and synchronising with a base station, the strongest correlation 32 would be used, even though this
25 corresponds to a longer path 42 than the earlier, weaker correlation 31. However, for the purpose of position identification, the straight line distance from the base station is required and so the time of arrival of the first correlation 31 is used, and not the strongest correlation 32. The first correlation may itself relate to a reflected signal, if there is no direct line of sight path, it will still be the closest to
30 the time a direct signal would have arrived.

The mobile unit M identifies from the respective BCCHs the times of arrival T_B , T_C , T_D , T_E of the first instance of the training sequence from each nearby base station B, C, D, E and compares them with the time of arrival T_A of

the training sequence from the serving base station A, to identify time intervals $T_1 = T_B - T_A$; $T_2 = T_C - T_A$; $T_3 = T_D - T_A$; $T_4 = T_E - T_A$. These intervals can be measured accurately by counting the number of digital bits which occur between the arrivals of these signals. This gives an accuracy of the order of 1 microsecond.

- 5 The intervals will be different, as a result of three factors: difference in path length; different relative frame offsets; and transmission in different frames. It is first necessary to eliminate the latter two factors in order to determine the differences in path length.

- Each base station transmits the same synchronisation training sequence
 10 five times in every control channel multiframe, that is at a time interval t_F . Since the mobile unit monitors control channel multiframes as a method of pre-synchronisation it will not always identify correlations from all the base stations A, B, C, D, E on the same part of the multiframe cycle structure. However, the time difference t_F between synchronisation bursts (SCH) within the control channel
 15 multiframe is large enough for a radio wave to propagate several thousand kilometres (approximately 13,800km), therefore multiples of the frame length can easily be eliminated.

- The different offsets of SCH within the mutiframe can be allowed for by measuring, at each base station, the time of transmission of the control channel
 20 mutiframe sequence relative to a universal reference such as the GPS synchronisation signal. The serving base station A transmits over the BCCH a signal representing the offsets of the neighbouring base stations (relative either to the universal reference or, preferably, relative to its own transmissions), thus allowing these offsets to be compensated for.

- 25 In this way a time difference $t_1 = T_1 - (n_1 t_F + Q_B)$ can be derived, where Q_B is the offset of base station B relative to base station A, t_F is the frame length, and n_1 is an integer, selected such that the magnitude of t_1 is a minimum. GPS provides time signals accurate to 50 nanoseconds, and this may be used at the base stations to provide the timing information required to determine the offset
 30 values. The frame length is a constant of the system. The accuracy of the value of t_1 is therefore determined largely by the accuracy with which T_1 is measured (typically of the order of 1 microsecond, as already discussed).

Note that the value of t_1 may be negative, if the base station B is closer to the mobile unit than the serving base station A, as may occur if the base station A has a stronger signal at the mobile unit than base station B, despite its greater distance, or if no traffic channel is available on base station B. As stated above,
 5 the interval between SCH frames is either 88 bursts or 80, and thus there are two possible values for t_F (46.15 or 50.77 milliseconds). The position within the multiframe can easily be determined by the mobile unit, and the appropriate value of t_F selected.

Values $t_2 = T_2 - (n_2 t_F + Q_C)$, $t_3 = T_3 - (n_3 t_F + Q_D)$, and $t_4 = T_4 - (n_4 t_F + Q_E)$ can be derived in a similar way.
 10

The values t_1 , t_2 , t_3 , and t_4 , when multiplied by c , the speed of propagation of radio waves, produce values d_1 , d_2 , d_3 , and d_4 which are the differences between path length d_a and the path lengths d_b , d_c , d_d , and d_e respectively (see Figure 1). Specifically, $d_1 = d_a - d_b$; $d_2 = d_a - d_c$; $d_3 = d_a - d_d$; and $d_4 = d_a - d_e$.
 15

It will be appreciated that the mobile unit has no means of detecting the GPS synchronisation pulse itself, as it is not a GPS receiver. The arrival times of the training sequences can therefore only be measured relative to each other, not against an absolute timescale, and therefore the time t_a it takes the training signal to reach the mobile unit M from the base station A is unknown. Thus the distance
 20 d_a of the mobile unit M from the base station A (which is simply the distance radio waves propagate in this unknown time t_a) cannot be derived directly (and similarly for base stations B, C, D, E). The relative arrival times indicate only that base station B, for example, is further from mobile unit M than base station A by a distance $d_1 = d_a - d_b$.

25 To enable the mobile unit to calculate its position, it has to know the location of the base station sites in its area. This information could be passed to the mobile unit by either using a "Cell Broadcast" message or a Short Message Service (SMS) as provided on some cellular systems; both are capable of message lengths up to an ample 160 characters. Information sent to the mobile unit from a
 30 base station would include; the co-ordinates of that base station, and information about the neighbouring base stations such as their locations and their offsets (the timing of the training sequence relative to a universal standard, or relative to the

serving base station), a flag to indicate if a base station was precisely synchronised, time, and date.

The serving base station A transmits not only its own details, but also details of its neighbours B, C, D, E. The mobile unit M can then get all the information it needs without having to handover to the other base stations. The rate at which such information is broadcast would have to be dimensioned to allow the mobile unit to calculate its position quickly, this would be especially important for a tracking service to make use of the information. The "Short Message Service" (SMS) available in the GSM system could be used when a customer initially requests the service, to provide authentication and prevent unauthorised use. Once a customer has been validated as a user, SMS could then pass a ciphering key to the mobile unit to allow it to decode the cell broadcast message. This system would be relatively secure as the messages passing over the radio interface are already protected by GSM's ciphering system.

SMS could be used instead of the Cell Broadcast system to pass all the base station site location information to a mobile unit and allow it to calculate its position. This method would be less prone to fraud than a Cell Broadcast, as SMS is a point to point system. However the large number of messages required to reach a potentially large number of mobile units could prove to be too high an overhead on the network. Another problem with an SMS based system is identifying which base station sites' details to send to a particular mobile unit without first knowing where the mobile unit is. Hence a mobile unit's serving base station ID would have to be known by the network before the information concerning its neighbouring base stations can be transmitted over SMS.

A tracking service would require the use of SMS originating from the mobile unit if the location were to be passed to a remote centre, for example the emergency services or a fleet control centre. Position information transmitted from the mobile unit could include a time stamp to allow for delays in the SMS network and the motion of the mobile unit.

The determination of position from timing differences will now be described in detail. It will be seen from the following that five base stations is the minimum necessary to ensure an unambiguous result in three dimensions if the

absolute distance from none of them is known. If only two dimensions are considered, four base stations are sufficient.

Figure 2 shows the information available to the mobile unit. (A star indicates that a value is unknown). The values x , y and z represent the mobile unit's position in three dimensions, which are to be calculated. The values X_a , etc indicate the known positions of the base stations, as transmitted to the mobile unit M over the BCCH.

Consider five base stations:

- Base station A at (X_a, Y_a, Z_a) : distance to mobile unit is d_a
 10 Base station B at (X_b, Y_b, Z_b) : distance to mobile unit is d_b
 Base station C at (X_c, Y_c, Z_c) : distance to mobile unit is d_c
 Base station D at (X_d, Y_d, Z_d) : distance to mobile unit is d_d
 Base station E at (X_e, Y_e, Z_e) : distance to mobile unit is d_e

15 The mobile unit scans the base stations and measures the timing differences t_1, t_2, t_3, t_4 between the serving base station and each surrounding base station, as described above. These timing differences are directly proportional to the path length differences: $d_i = t_i c$, where c is the speed of propagation of radio waves, approximately 300 metres per microsecond. Hence
 20 the mobile unit can easily calculate d_1 to d_4 where;

$$d_1 = d_a - d_b$$

$$d_2 = d_a - d_c$$

$$d_3 = d_a - d_d$$

$$d_4 = d_a - d_e$$

25

The following five equations represent the mobile unit's location, based on the equation for a sphere;

$$(x - X_a)^2 + (y - Y_a)^2 + (z - Z_a)^2 = d_a^2$$

- Equation [1]

$$(x - X_b)^2 + (y - Y_b)^2 + (z - Z_b)^2 = d_b^2$$

- Equation [2]

30 $(x - X_c)^2 + (y - Y_c)^2 + (z - Z_c)^2 = d_c^2$

- Equation [3]

$$(x - X_d)^2 + (y - Y_d)^2 + (z - Z_d)^2 = d_d^2$$

- Equation [4]

$$(x - X_e)^2 + (y - Y_e)^2 + (z - Z_e)^2 = d_e^2$$

- Equation [5]

Now, $d_1 = d_a - d_b$. Rewritten as $d_1 - d_a = -d_b$, and squaring both sides gives;

$$d_1^2 - 2d_1d_a + d_a^2 = d_b^2 \quad \text{- Equation [6]}$$

Substitute [1] and [2] into [6];

$$5 \quad d_1^2 - 2d_1d_a + (x - X_a)^2 + (y - Y_a)^2 + (z - Z_a)^2 = (x - X_b)^2 + (y - Y_b)^2 + (z - Z_b)^2$$

Rearranging to put known variables on the right hand side gives;

$$-d_1d_a - x(X_a - X_b) - y(Y_a - Y_b) - z(Z_a - Z_b) = k_1/2 \quad \text{- Equation (7a)}$$

10

Where k_1 consists of the known values;

$$k_1 = -d_1^2 - X_a^2 - Y_a^2 - Z_a^2 + X_b^2 + Y_b^2 + Z_b^2$$

For simplicity we define;

$$15 \quad X_{ab} = X_a - X_b,$$

$$Y_{ab} = Y_a - Y_b,$$

$$\text{and: } Z_{ab} = Z_a - Z_b.$$

Equation 7a becomes;

$$20 \quad -d_1d_a - xX_{ab} - yY_{ab} - zZ_{ab} = k_1/2 \quad \text{- Equation [7]}$$

Repeating this process with equations [3] to [5] gives;

Base stations A and C

$$-d_2d_a - xX_{ac} - yY_{ac} - zZ_{ac} = k_2/2 \quad \text{- Equation [8]}$$

$$25 \quad \text{Where; } k_2 = -d_2^2 - X_a^2 - Y_a^2 - Z_a^2 + X_c^2 + Y_c^2 + Z_c^2$$

Base stations A and D

$$-d_3d_a - xX_{ad} - yY_{ad} - zZ_{ad} = k_3/2 \quad \text{- Equation [9]}$$

$$\text{Where } k_3 = -d_3^2 - X_a^2 - Y_a^2 - Z_a^2 + X_d^2 + Y_d^2 + Z_d^2$$

30

Base stations A and E

$$-d_4d_a - xX_{ae} - yY_{ae} - zZ_{ae} = k_4/2 \quad \text{- Equation [10]}$$

$$\text{Where } k_4 = -d_4^2 - X_a^2 - Y_a^2 - Z_a^2 + X_e^2 + Y_e^2 + Z_e^2$$

Rearranging equation [7] in terms of d_a ;

$$d_a = \frac{-1}{d_1} \left(\frac{k_1}{2} + xX_{ab} + yY_{ab} + zZ_{ab} \right) \quad - \text{Equation [11]}$$

5 Substitution of [11] into [8] leads to;

- Equation [12]

$$x(X_{ab}d_2 - X_{ac}d_1) + y(Y_{ab}d_2 - Y_{ac}d_1) + z(Z_{ab}d_2 - Z_{ac}d_1) - \left(\frac{d_1k_2 - d_2k_1}{2} \right) = 0$$

Substitution of [11] into [9] leads to;

- Equation [13]

$$x(X_{ab}d_3 - X_{ac}d_1) + y(Y_{ab}d_3 - Y_{ac}d_1) + z(Z_{ab}d_3 - Z_{ac}d_1) - \left(\frac{d_1k_3 - d_3k_1}{2} \right) = 0$$

10

Substitution of [11] into [10] leads to;

- Equation [14]

$$x(X_{ab}d_4 - X_{ac}d_1) + y(Y_{ab}d_4 - Y_{ac}d_1) + z(Z_{ab}d_4 - Z_{ac}d_1) - \left(\frac{d_1k_4 - d_4k_1}{2} \right) = 0$$

For two-dimensional positioning, all z co-ordinates can be ignored. This will induce an error due to the fact that the four base stations and the mobile unit are unlikely to all be in exactly the same plane. In particular, base stations are, whenever possible, mounted on hills or tall structures (buildings or purpose-built masts) to improve their range, whilst mobile units generally to operate near ground level. However, when the differences in altitude are small (of the order of the accuracy of the system as a whole) the error will be insignificant.

Subject to these limitations, we can solve in two dimensions by ignoring the z co-ordinates from the equations and from the calculation of the terms k_1 , k_2 , etc. Equation [12] then becomes;

$$x(X_{ab}d_2 - X_{ac}d_1) + y(Y_{ab}d_2 - Y_{ac}d_1) - \left(\frac{d_1k_2 - d_2k_1}{2} \right) = 0$$

25

and equation [13] becomes;

$$x(X_{ab}d_3 - X_{ac}d_1) + y(Y_{ab}d_3 - Y_{ac}d_1) - \left(\frac{d_1k_3 - d_3k_1}{2} \right) = 0$$

Both of these equations represent straight lines in the x y plane. The point where these two lines cross represents the mobile unit's position. This point can be found by substituting one equation into the other.

- 5 In three dimensions equations [12], [13] and [14] each represent planes in space. The intersection of two planes represents a straight line, hence all three equations are needed to find the mobile unit location (x, y, z) uniquely.

The general equation of a plane is; $Ax + By + Cz + D = 0$

10

For equation [12]; $A = X_{ab}d_2 - X_{ac}d_1$; $B = Y_{ab}d_2 - Y_{ac}d_1$; $C = Z_{ab}d_2 - X_{ac}d_1$; and

$$D = -\left(\frac{d_1k_2 - d_2k_1}{2}\right)$$

To solve the intersection of the three planes, the equations need to be put into Hessian form. For equation [12];

15

$$n_1^2 = \frac{A^2}{A^2 + B^2 + C^2} \quad n_2^2 = \frac{B^2}{A^2 + B^2 + C^2}$$

$$n_3^2 = \frac{C^2}{A^2 + B^2 + C^2} \quad p^2 = \frac{D^2}{A^2 + B^2 + C^2}$$

The plane can now be simply represented as a vector;

$$nx = -p, \text{ where: } n = n_1i + n_2j + n_3k$$

20

Once all the planes are represented in this form, the intersection can easily be calculated.

- 25 The calculation using timing differences described above can be carried out in the mobile unit with very little network overhead. This system will be able to support a large number of users as it does not necessitate calls to be made, apart from initial authenticating SMS messages. It should be noted that much of the software required to process time difference information already exists in mobile units. However, the system does require the addition of special software in the mobile unit to perform the necessary calculations. Improvements in the signal processing, for example by using data retrieved from the mobile unit's equaliser,
- 30

may also be used to resolve to rather better than the $\frac{1}{4}$ bit (0.923 microseconds, equivalent to 277 metres) needed purely for bit synchronisation. The data present in the equaliser of the mobile unit should allow resolution to 4% of one bit, equivalent to approximately 50 metres.

- 5 Factors such as multipath, shadowing and fading may cause the accuracy of the location calculation to vary with time. Therefore, it is desirable to use time averaging in the location calculation algorithm to improve the accuracy.

 There are a number of possible services that could be provided as adjuncts to a positioning service. Large amounts of money are defrauded from the cellular
10 radio industry by illegal practices such as, "cloning", which is the fraudulent practice of giving one mobile unit, usually a stolen one, the electronic identity of another, legitimate, unit. Calls made on the "clone" are then charged by the cellular network to the legitimate user. The existence of a clone is usually only detected when the legitimate user gets his bill, or if both the clone and legitimate
15 user attempt to access the system simultaneously. Providing a built-in location service would mean that a stolen or otherwise suspicious mobile unit could be quickly located and recovered.

 Similarly, a mobile unit built into a vehicle would enable the vehicle to be located, if it should be stolen. For such services to be effective the location
20 software would have to be enabled remotely, either by the official owners or by the police.

 Accurate positional information would prove invaluable to the emergency services in other ways. The service would allow help to be directed quickly and efficiently to a person in distress making an emergency call from a mobile unit so
25 fitted. It may be desirable that the customer has control as to whether the service is activated, to avoid any customer perception that they are under surveillance by the authorities.

 The emergency services, and other organisations with large field forces such as utility companies, may themselves make use of the cellular network, in
30 place of a private mobile network (PMR), and the tracking service would allow a controller to monitor the distribution of his field force personnel.

 A tracking service can also be used to monitor the progress of valuable or sensitive cargoes. The system could be arranged to warn of deviations from a

preset route. Another application could be an alarm service to alert weary train travellers when they reach their home station.

As stated above, a signal needs to be received from four base stations in order to provide a position fix in two dimensions, (five base stations for three dimensions). There are some circumstances when fewer base stations are within
5 range. In these circumstances various supplementary methods may be used to obtain a position fix.

In one possible arrangement the mobile unit may be forced to hand over from the currently serving base station A to a neighbouring base station, for
10 example Base Station B (see Figure 1). This base station will have a different "neighbour list" from that of Base Station A (although the lists will have several base stations in common). Between the two neighbour lists there may be sufficient base stations in range of the mobile unit for a fix to be obtained. The base stations in each neighbour list will each have their offsets determined according to the
15 respective base station A or B, but this can be allowed for because the offset of base station B relative to base station A is known, since they are in each other's neighbour lists.

Other supplementary methods may also be employed. For example the absolute distance to the currently serving base station may be derived from the
20 timing advance; that is, the amount by which the mobile unit's transmissions need to be advanced relative to the signals received from the base station such that they arrive at the base station in the correct time slot. This is only accurate to about 600 metres, and the timing advance is normally only calculated when a call is in progress, not when the mobile unit is on standby.

25 As shown in Figure 1 for base station A, one (or more) cells may be sectorised, that is, the base station has several antennas each serving a limited azimuthal range (typically 60 or 120 degrees). Identification of the sector A1 serving the mobile unit may be used to identify which solution of the equations is correct. However, this method is not practical where the base station has an
30 omnidirectional antenna, nor where two or more possible results all occur in the same sector A1. In particular, since the sectoring is azimuthal, it will not resolve an ambiguity in the z coordinate (altitude). Furthermore, there is a possibility that a side or rear lobe of the sector antenna might be detected.

A further possibility is to identify, from the possible solutions, the one which is closest to the previously identified location of the mobile unit as being the one most likely to be the new one. This can be reasonably reliable if the mobile unit is travelling slowly in comparison to the time between location updates.

5 Figure 1 also shows a microcell H. Microcells are very small cells served by low power base stations often mounted well below roof-top level or even indoors to provide additional coverage in locations of very high demand. It is very likely that a GPS receiver would not operate in such a base station, as it would not be reliably visible to the satellites, as well as being cost prohibitive. Moreover,
10 because the antenna of the microcell H is likely to be at low level or indoors it is probable that a mobile unit in range of a microcell base station is not in radio range of as many as four base stations, and possibly is in range of no base station other than that serving the microcell H. However, because the microcell H only covers a very small area, the information that the mobile unit M is within range of the
15 microcell H can give sufficient accuracy to locate the mobile unit to the same accuracy as the basic system.

All of these supplementary processes have the potential for systematic errors, and lower accuracy than the basic system, and also require additional processing, but may be used, individually or in combination, to maintain the service
20 when fewer base stations than the minimum four (five) are within range of the mobile unit.

The GPS system has systematic errors in it, resulting in an accuracy of about 100 metres. For some applications, such as surveying, greater accuracy is required, and a system known as "differential GPS" has been developed to
25 overcome this. This involves placing a GPS receiver at a precisely known "beacon" position and measuring the error in its position as measured by GPS, which error value is then transmitted to other users. The position location system of the present invention requires a significant number of cellular base stations to have GPS receivers fitted, to provide accurate synchronising signals. Since the
30 positions of the cellular base stations are fixed, they can be determined by other means with great accuracy, allowing them to be used to offer such a differential GPS beacon service.

CLAIMS

1. A method of determining the location of a mobile unit of a cellular radio system having a plurality of base stations, comprising the steps of determining the differences in timing between the base stations' transmissions as measured at the
5 mobile unit, determining from the timing differences the differences in the distance of the mobile unit from each of the base stations, and deriving the location of the mobile unit from the differences in distance so determined, characterised in that the time division frame structures of the control channels of at least some of the base stations within radio range of the mobile unit are synchronised, and the
10 mobile unit determines the differences in timing at the mobile unit of a characteristic feature of the time division frame structure broadcast by the control channel of each base station.
2. A method according to claim 1, in which the differences in timing between at least four base stations are determined, thereby allowing the determination of
15 the absolute location of the mobile unit in two dimensions.
3. A method according to claim 1, in which the differences in timing between at least five base stations are determined, thereby allowing the determination of the absolute location of the mobile unit in three dimensions.
4. A method according to claim 2 or claim 3, wherein if fewer than the
20 required number of base stations are detected by the mobile unit, the timing advance required for communication with the serving base station is used to derive the distance between the mobile unit and the serving base station.
5. A method according to claim 2, 3, or 4, wherein if fewer than the required
25 number of base stations are detected by the mobile unit, information relating to the direction of the mobile unit relative to one or more of the base stations is additionally used to identify the correct location.

6. A method according to any preceding claim, in which the base stations' time division frame structures' timings are offset relative to each other, and in which for each base station the respective offset is subtracted from the arrival time of the characteristic feature of the frame to obtain the difference between the distance that base station is from the mobile unit and the distance the serving base station is from the mobile unit.
7. A method according to claim 6, wherein data relating to the offset associated with each base station is transmitted from the serving base station to the mobile unit, and the distance calculation is determined by the mobile unit from said offset data and the arrival times of the characteristic feature.
8. A method according to any preceding claim, in which the characteristic feature used is a training signal transmitted by each base station, and the mobile unit identifies correlations of the signals received from each base station with a reference training signal stored by the mobile unit.
9. A method according to claim 8, in which the cellular radio system operates according to the GSM standard, and the training signal is the synchronisation burst (SCH) transmitted according to that standard.
10. A method according to claim 8 or claim 9, in which the first identified correlation of the reference signal, corresponding to the most direct signal path, is used for distance calculation.
11. A method according to any preceding claim, in which the derived location is time averaged.
12. A method according to any preceding claim, wherein one or more of the plurality of base stations in the cellular radio system have a very short range, and comprising the additional step wherein if the mobile unit is recognised as being within range of one of said limited-range base stations the location of the mobile unit is determined to be the location of said limited-range base station.
13. A method according to any preceding claim, wherein the derived location is communicated via the cellular radio network to a remote user.

14. A method according to any preceding claim, wherein, if the derived location corresponds to a predetermined location, an alarm signal is transmitted.

15. Mobile unit for use with a cellular radio system, the mobile unit comprising apparatus for determining the position of the mobile unit; the apparatus comprising
5 means for detecting timing differences of signals received from different radio base stations, and means for determining, from the timing differences, the differences in the distances of the mobile unit from each of the base stations; and means for deriving, from the differences in distance, the location of the mobile unit, characterised in that the mobile unit has means for determining the differences in
10 timing at the mobile unit of a characteristic feature of a time division frame structure broadcast synchronously by the control channel of each base station.

16. Mobile unit according to claim 15 comprising means for detecting the differences in timing at the mobile unit of at least four base stations, and means for thereby determining the position of the mobile unit in two dimensions.

15 17. Mobile unit according to claim 15 comprising means for detecting the differences in timing at the mobile unit of at least five base stations, and means for thereby determining the position of the mobile unit in three dimensions.

18. Mobile unit according to claim 16 or 17, having means for deriving the distance between the mobile unit and the serving base station from the timing
20 advance required for communication with the serving base station if fewer than the required number of base stations are detected by the mobile unit.

19. Mobile unit according to 16, 17 or 18, having means for determining the direction of the mobile unit relative to one or more of the base stations if fewer than the required number of base stations are detected by the mobile unit.

25

20. Mobile unit according to claim 15, 16, 17, 18 or 19 further comprising means for receiving data concerning the location of the base stations.

21. Mobile unit according to claim 20 further comprising means for receiving data concerning the amount by which the base stations' frame timings are offset relative to the currently serving base station, and means for subtracting, for each base station, the offset from the arrival time of the frame to obtain the difference
5 between the distance between that base station and the mobile unit, and the distance between the serving base station and the mobile unit.

22. Mobile unit according to any of claims 15 to 21, arranged to operate according to the GSM standard, and wherein the characteristic feature is the
10 synchronisation burst (SCH) transmitted according to that standard.

23. Mobile unit according to any of claims 15 to 22, further comprising means for identifying the base stations within radio range of the mobile unit.

15 24. Mobile unit according to any of claims 15 to 23, further comprising means for identifying a predetermined geographical location, and alarm means for signalling to a user that the geographical location of the device corresponds to the predetermined location.

20 25. A cellular radio network for use with the mobile unit of any of claims 21, 22, 23 or 24, comprising a plurality of base stations operating with control channels broadcasting synchronous time division frame structures, means for identifying which of the base stations are in radio range of a specified mobile unit, and means for transmitting data relating to the location and synchronisation offset
25 of each such base station to the mobile unit.

26. A cellular radio network comprising a plurality of base stations operating with control channels broadcasting synchronous time division frame structures, means for identifying which of the base stations are in radio range of a specified mobile unit, means for identifying the difference in timing between signals
5 transmitted by the base stations as measured at the mobile unit; means for determining, from the timing differences, the differences in the distances of the mobile unit from each of the base stations; and means for deriving, from the differences in distance, the location of the mobile unit, characterised in that the base stations have broadcast control channels operating with synchronised time
10 division frame structures having a characteristic feature for detection by the mobile units, and in having means for receiving from the mobile unit an indication of the arrival time at the mobile unit of the characteristic feature transmitted from each base station.

27. Cellular radio network according to claim 25 or 26, arranged to operate
15 according to the GSM standard, and wherein the characteristic feature is the synchronisation burst (SCH) transmitted according to that standard.

28. Cellular radio network according to claim 25, 26 or 27, comprising means for detecting the differences in timing at the mobile unit of at least four base stations, and means for thereby determining the position of the mobile unit in two
20 dimensions.

29. Cellular radio network according to claim 25, 26 or 27, comprising means for detecting the differences in timing at the mobile unit of at least five base stations, and means for thereby determining the position of the mobile unit in three dimensions.

25 30. Cellular radio network according to claim 27, 28, or 29, having means for deriving the distance of the mobile unit from the serving base station from the timing advance required for communication with the serving base station, if fewer than the required number of base stations are detected by the mobile unit.

31. Cellular radio network according to claim 27, 28, 29 or 30, having means for determining the direction of the mobile unit relative to one or more of the base stations if fewer than the required number of base stations are detected by the mobile unit.
- 5 32. Cellular radio system according to any of claims 26 to 31, in which the base stations' frame timings are offset relative to each other, and further comprising means for subtracting the respective offset from the arrival time of the characteristic feature of the frame at the mobile unit to obtain the difference between the distance that base station is from the mobile unit and the distance the
10 serving base station is from the mobile unit.
33. Apparatus for determining the position of a mobile unit using a cellular radio system having a plurality of base stations, comprising means for determining the differences in timing of the operation of the base stations as measured at the mobile unit; means for determining, from the timing differences, the differences in
15 the distances of the mobile unit from each of the base stations; and means for deriving, from the differences in distance, the location of the mobile unit, characterised in that the system comprises means for synchronising the time division frame structures of control channels broadcast by at least a plurality of the base stations within radio range of the mobile unit, and the mobile unit has means
20 for determining the differences in timing at the mobile unit of a characteristic feature of the time division frame structure broadcast by the control channel of each base station.
34. Apparatus according to claim 33, wherein the time difference measuring means, distance difference determining means and location deriving means form
25 part of the mobile unit.
35. Apparatus according to claim 34, further comprising means for identifying the base stations within radio range of the mobile unit, and means for transmitting data to the mobile unit relating to the geographical locations of said base stations.

36. Apparatus according to claim 33, 34, or 35 further comprising means for determining and compensating for offsets in synchronisation between the base stations' transmissions.
37. Apparatus according to any of claims 33 to 36, arranged to operate
5 according to the GSM standard, and wherein the characteristic feature is the synchronisation burst (SCH) transmitted according to that standard.
38. Apparatus according to any of claims 33, 34, 35, 36 or 37 comprising means for detecting the differences in timing at the mobile unit of at least four base stations, and means for thereby determining the position of the mobile unit in
10 two dimensions.
39. Apparatus according to any of claims 33, 34, 35, 36, 37 or 38 comprising means for detecting the differences in timing at the mobile unit of at least five base stations, and means for thereby determining the position of the mobile unit in 3 dimensions.
- 15 40. Apparatus according to claim 38 or 39, having means for deriving the distance of the mobile unit from the serving base station from the timing advance required for communication with the serving base station, if fewer than the required number of base stations are detected by the mobile unit.
41. Apparatus according to claim 38, 39 or 40, having means for determining
20 the direction of the mobile unit relative to one or more of the base stations, if fewer than the required number of base stations are detected by the mobile unit.
42. Position-finding device comprising means for determining the geographical location of the device, means for identifying a predetermined geographical location, and alarm means for signalling to a user that the geographical location of the
25 device corresponds to the predetermined location.
43. Method of determining location of a cellular telephone, substantially as described with reference to the drawings.
44. Apparatus for determining the location of a cellular telephone, substantially as described with reference to the drawings.

1/4

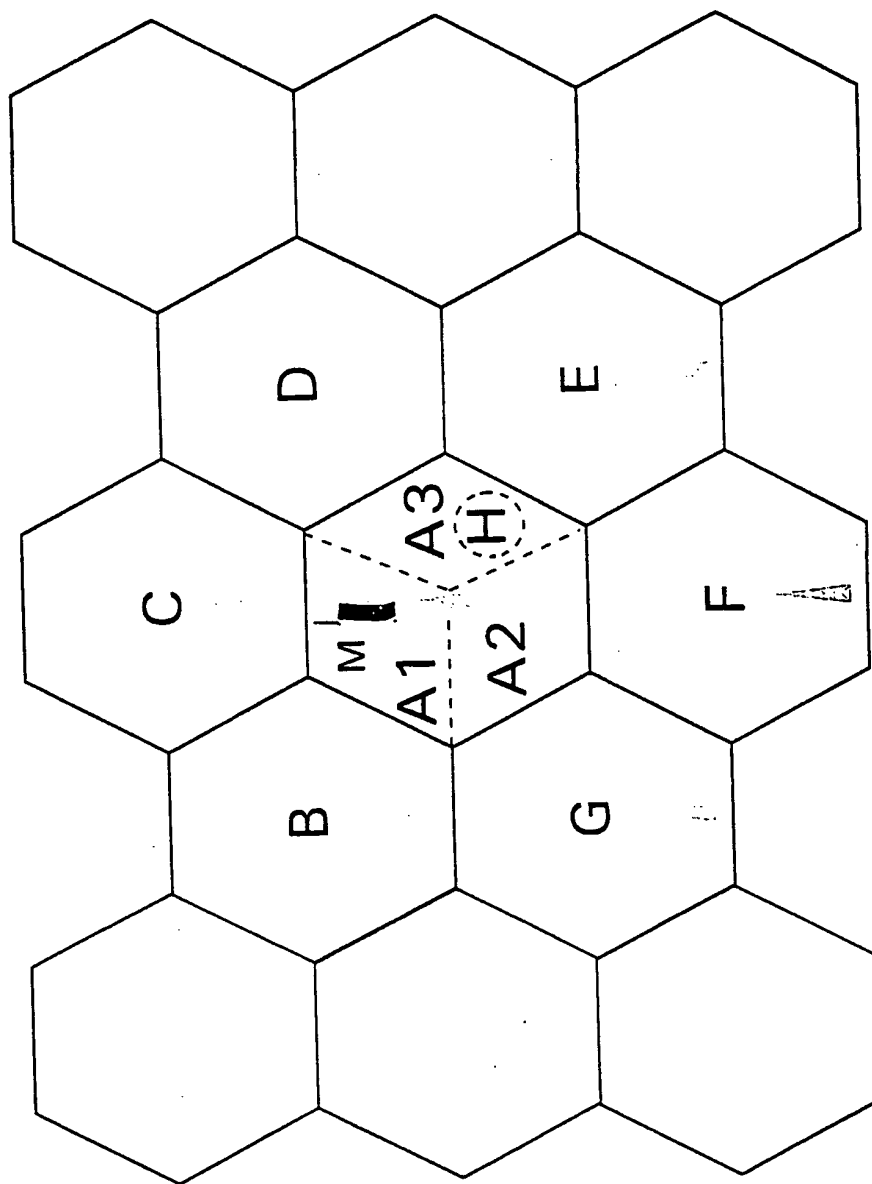


FIGURE 1

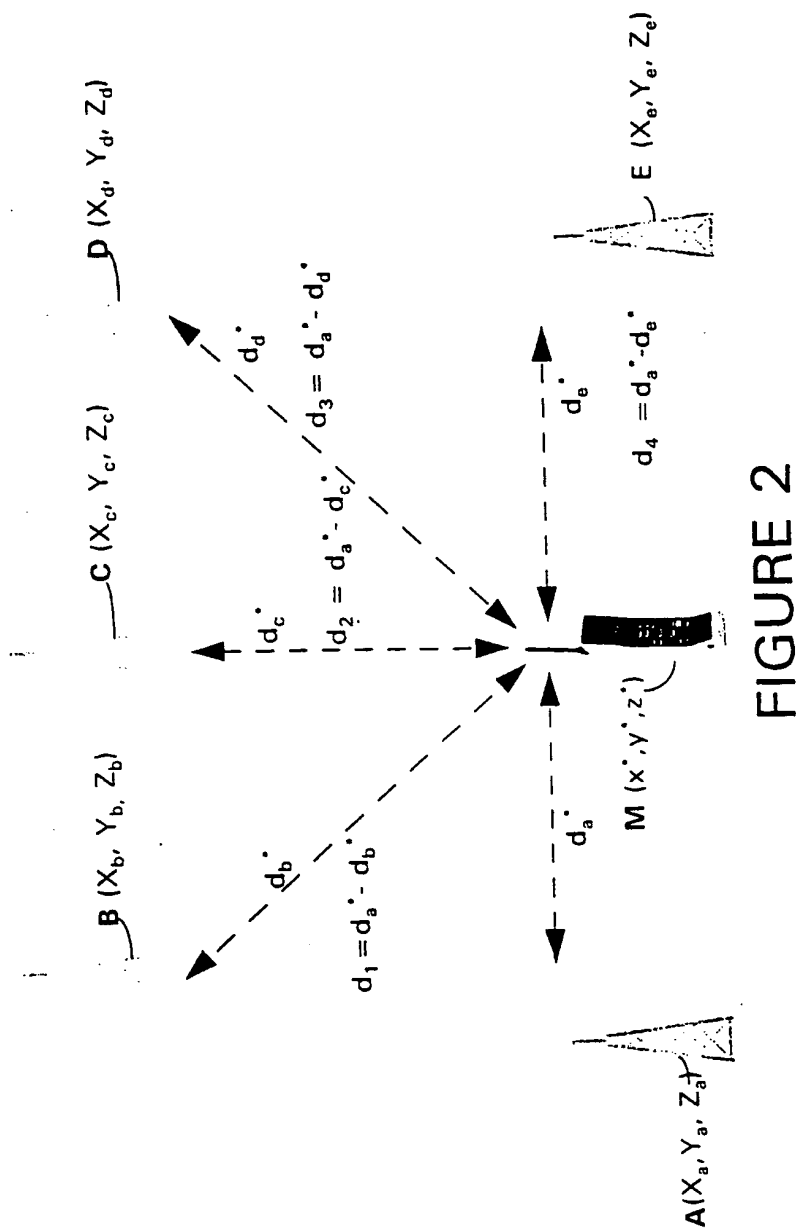


FIGURE 2

3/4

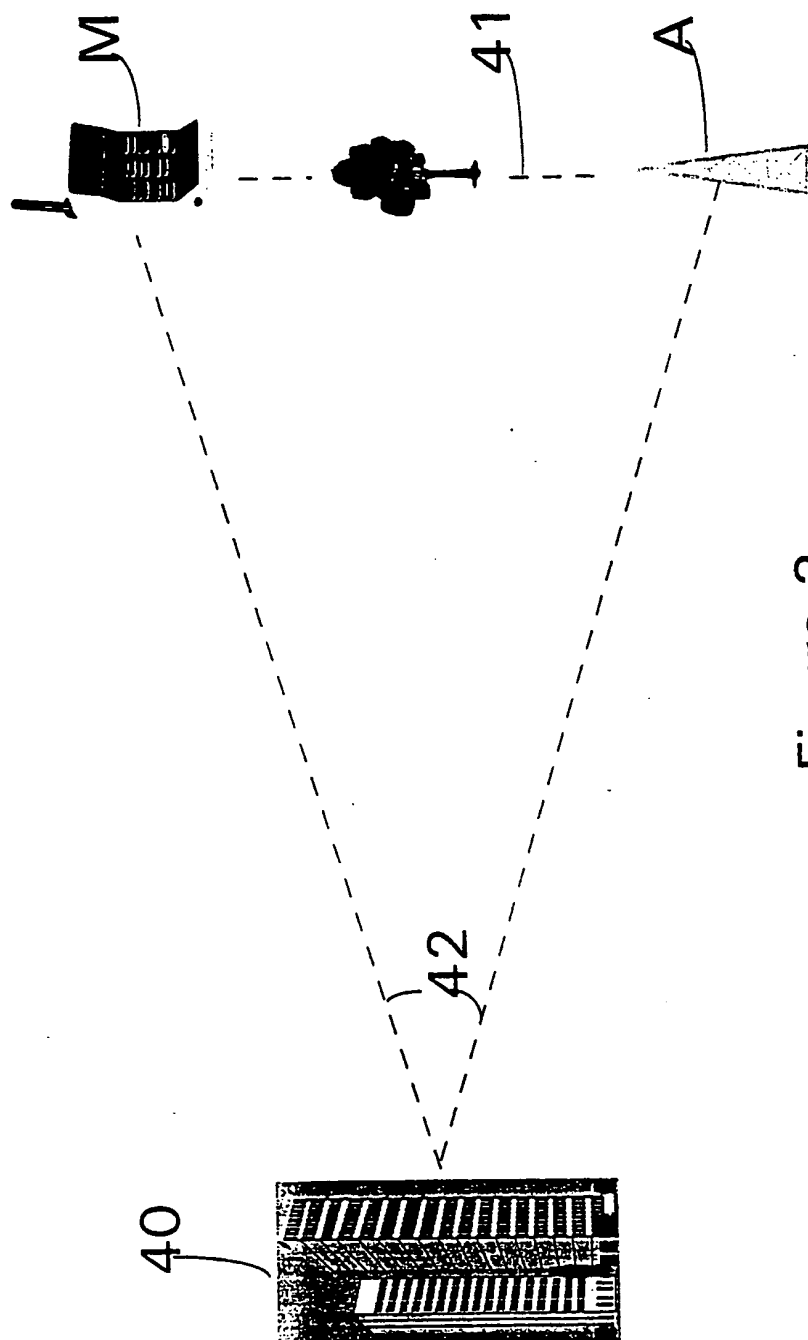


Figure 3

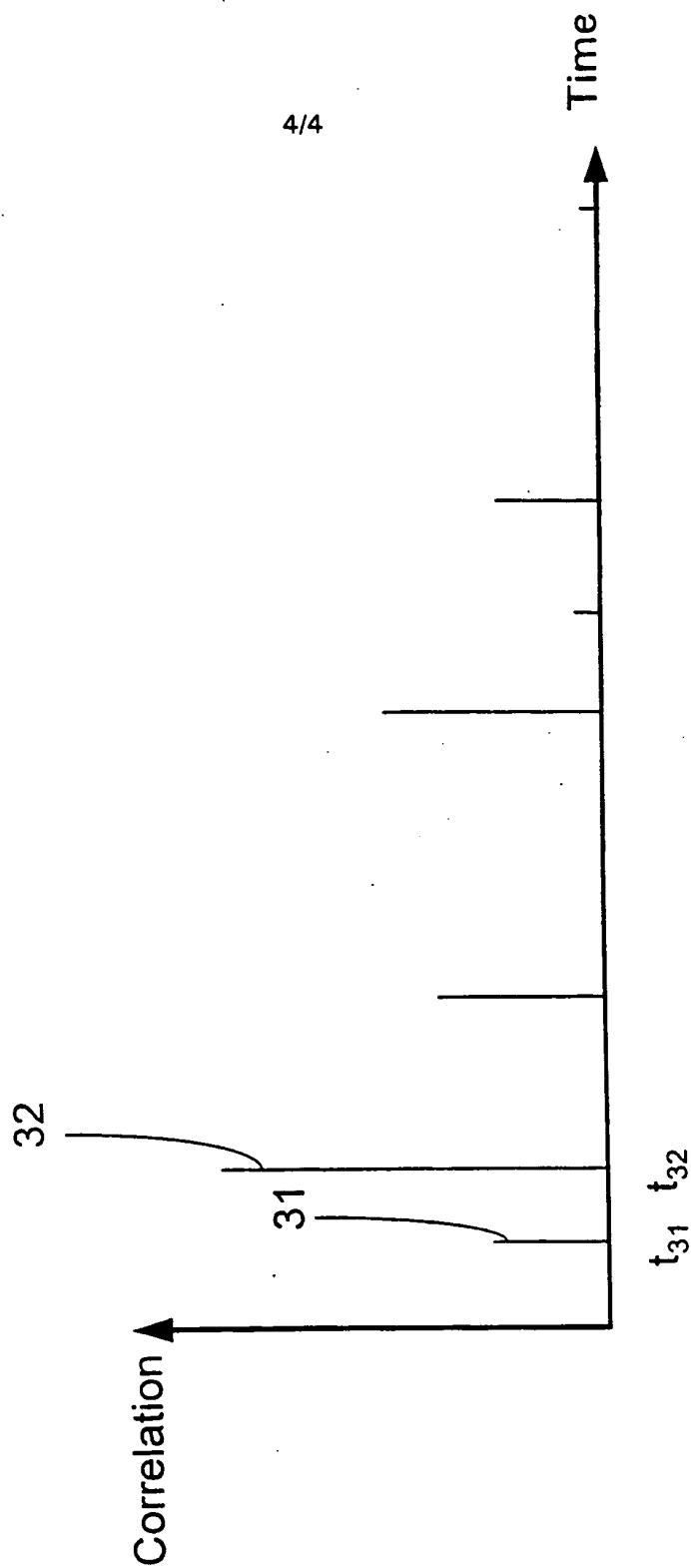


Figure 4

INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 96/01039

A. CLASSIFICATION OF SUBJECT MATTER
 IPC 6 H04Q7/38 G01S5/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
 IPC 6 H04Q G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>US,A,5 293 645 (S00D PREM L) 8 March 1994</p> <p>see column 2, line 14 - column 3, line 40 see column 4, line 33 - column 5, line 6 see column 6, line 35 - line 40 see column 6, line 43 - column 7, line 8 --- -/--</p>	<p>1-4,6, 15-18, 26,28, 29,32, 33,36, 38,39</p>

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

- * "A" document defining the general state of the art which is not considered to be of particular relevance
- * "E" earlier document but published on or after the international filing date
- * "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- * "O" document referring to an oral disclosure, use, exhibition or other means
- * "P" document published prior to the international filing date but later than the priority date claimed

* "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

* "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

* "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

* "&" document member of the same patent family

Date of the actual completion of the international search

9 August 1996

Date of mailing of the international search report

- 3. 09. 96

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
 NL - 2280 HV Rijswijk
 Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl,
 Fax (+ 31-70) 340-3016

Authorized officer

Gerling, J.C.J.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 96/01039

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>WO,A,95 00821 (OMNIPLEX INC) 5 January 1995 cited in the application</p> <p>see page 3, line 20 - line 29 see page 4, line 4 - line 19 see page 7, line 13 - line 29 see page 8, line 4 - line 13 see page 9, line 26 - page 10, line 34 see page 12, line 1 - line 16 see page 14, line 20 - line 26 see page 16, line 12 - line 31 see page 17, line 18 - page 19, line 25</p> <p>---</p>	<p>1-3,8, 15-17, 20,21, 23,26, 28,29, 32-36, 38,39</p>
A	<p>EUROPEAN TRANSACTIONS ON TELECOMMUNICATIONS AND RELATED TECHNOLOGIES, vol. 5, no. 2, 1 March 1994, MILANO (IT), pages 245-260, XP000453466 HANZO L ET AL: "THE PAN-EUROPEAN MOBILE RADIO SYSTEM PART I" see page 124, paragraph 6. - page 127, paragraph 8. see page 120, paragraph 3. - page 121, paragraph 4.</p> <p>---</p>	<p>1,15,26, 33</p>
X	<p>EP,A,0 241 565 (ANT NACHRICHTENTECH) 21 October 1987 see column 3, line 1 - column 5, line 17</p> <p>---</p>	<p>1,15</p>
X	<p>WO,A,92 05672 (TELEVERKET) 2 April 1992 see page 3, line 33 - page 7, line 5</p> <p>---</p>	<p>1,15,26, 33</p>
X	<p>EP,A,0 588 086 (AISIN AW CO., LTD.) 23 March 1994 see claim 1</p> <p>-----</p>	<p>42</p>

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB 96/01039

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-5293645	08-03-94	JP-A- 5211470	20-08-93
WO-A-9500821	05-01-95	AU-B- 7173694	17-01-95
EP-A-0241565	21-10-87	NONE	
WO-A-9205672	02-04-92	SE-B- 466376	03-02-92
		DE-D- 69119085	30-05-96
		EP-A- 0551310	21-07-93
		JP-T- 6500902	27-01-94
		SE-A- 9002920	03-02-92
EP-A-588086	23-03-94	JP-A- 6066576	08-03-94
		JP-A- 6066581	08-03-94
		JP-A- 6066587	08-03-94
		JP-A- 6066588	08-03-94

**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

☒ **BLACK BORDERS**

☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**

☒ **FADED TEXT OR DRAWING**

☒ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**

☐ **SKEWED/SLANTED IMAGES**

☐ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**

☐ **GRAY SCALE DOCUMENTS**

☐ **LINES OR MARKS ON ORIGINAL DOCUMENT**

☒ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**

☐ **OTHER:** _____

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.